STORAGE R&D PROGRAM LESSONS LEARNED

December 2014

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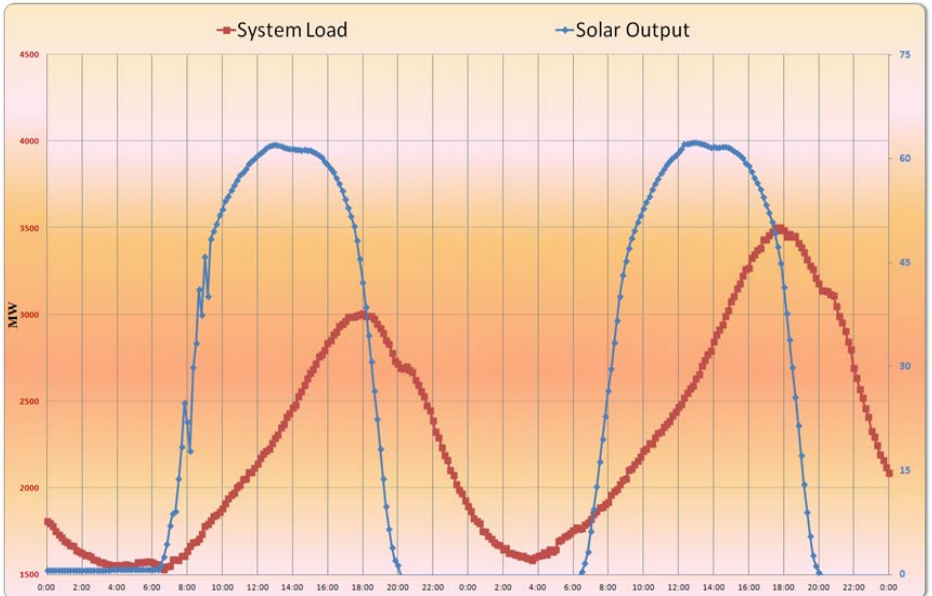
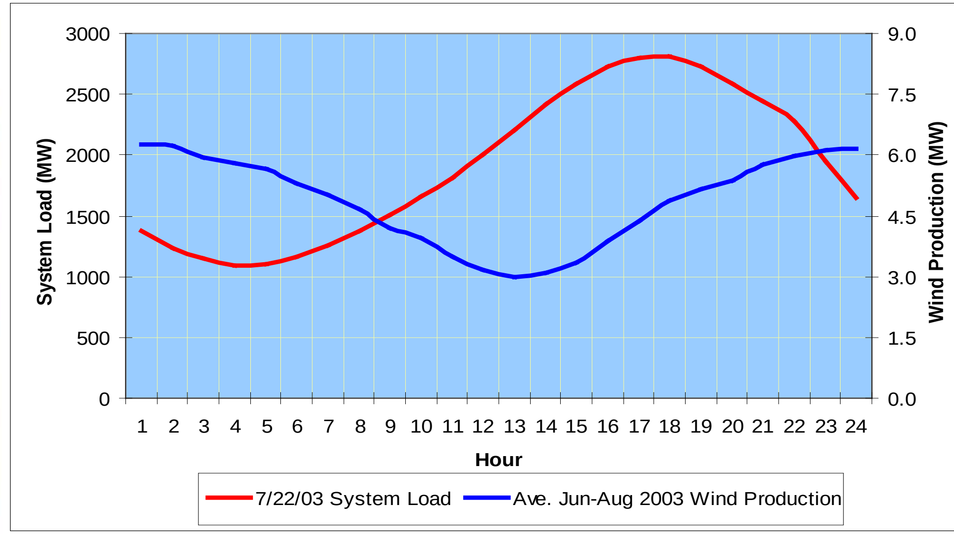
Powering forward. Together.

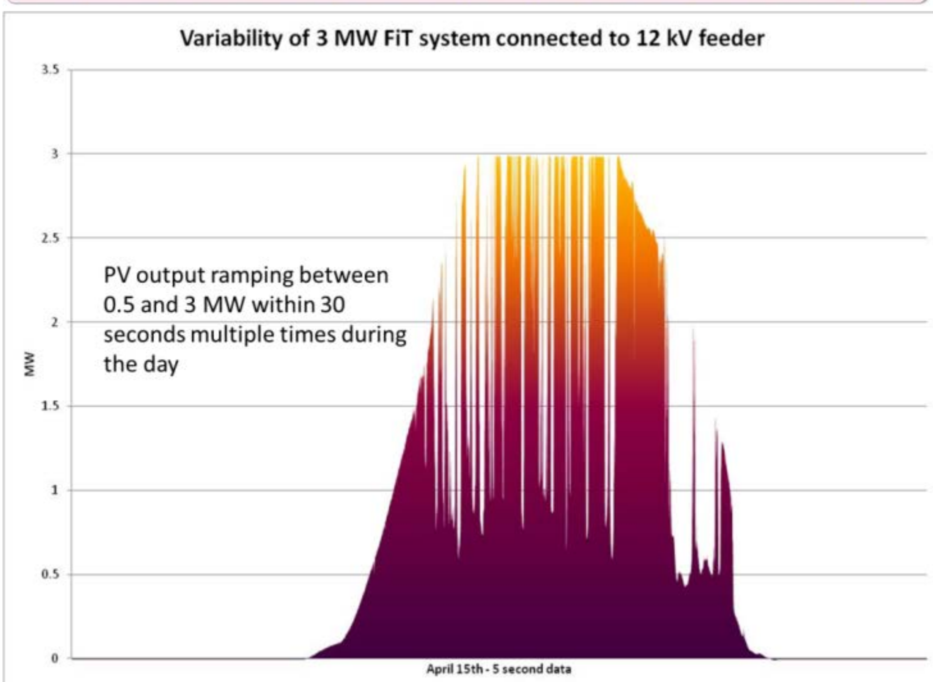
Storage Could Be Mitigation Strategy For High Penetrations Of PV and Wind

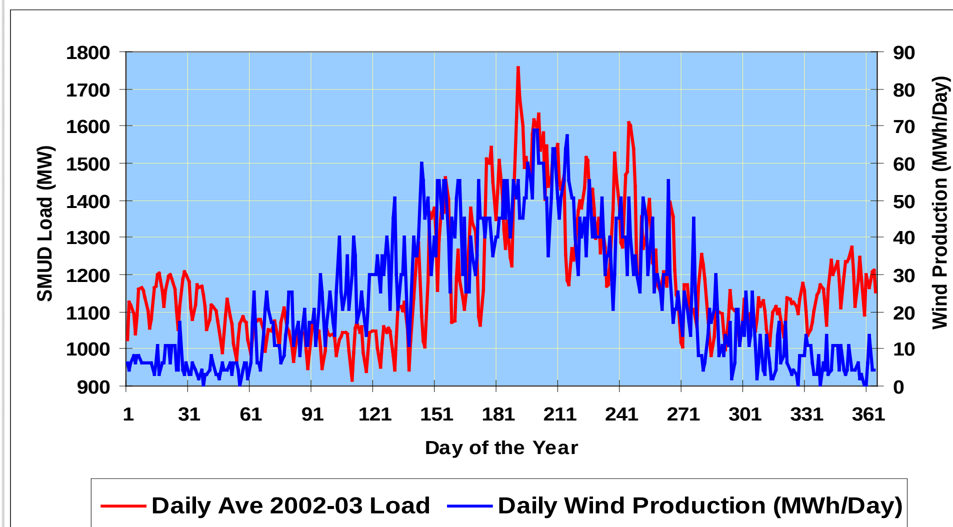
- Believe SMUD will need bulk **and** distributed storage in long run
- Questions of what kind, how much of it and when, and how much will it cost
- Pursuing a multi-pronged research approach:
  - Developing improved understanding of storage technologies
  - Determining the benefits of distributed storage to SMUD
  - Conducting some distributed storage system demonstrations, monitoring performance and cost effectiveness
  - Preparing SMUD for energy storage utilization

Intermittent Renewables Challenges





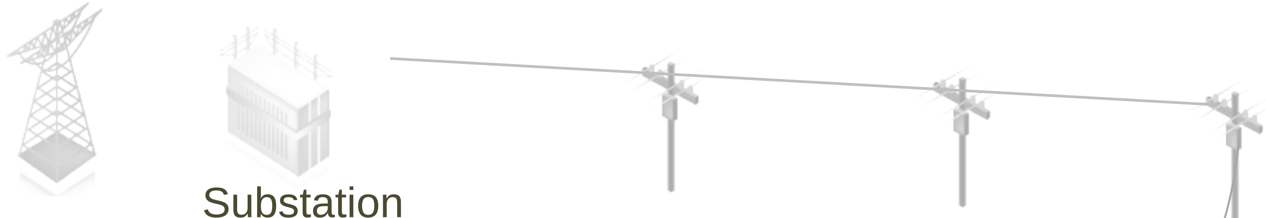




SMUD Storage R&D Portfolio

Transmission

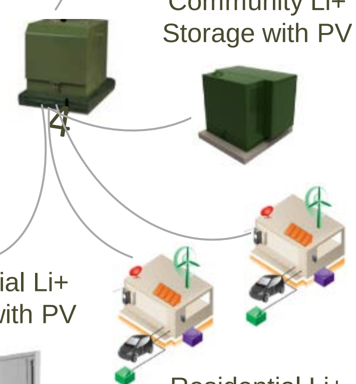
Distribution



Substation

Utility Scale PV with
Li+ Storage

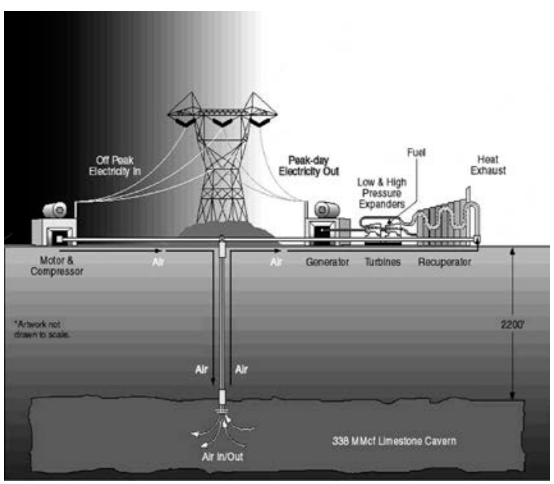
Community Li+
Storage with PV



Wind and Large PV
with Compressed
Air Energy Storage

Residential Li+
Storage with PV

Residential Li+
Storage with PV



Commercial Scale PV
with NaNiCl Storage

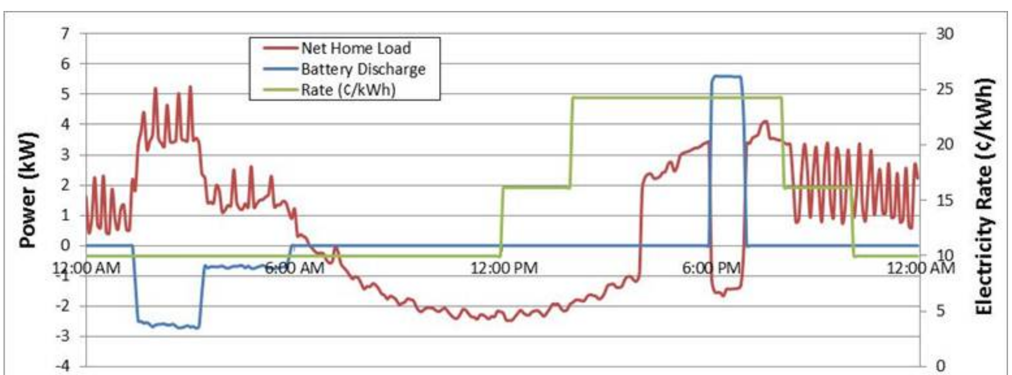
SMUD Storage R&D Portfolio

Project Name	Technology	Status	# of Units	Capacity	Energy
Anatolia PV and Storage Demo	Lithium ion	Decommissioned; final report published	3 15	30 kW 5 kW	34 kWh 8.8 kWh
PV, EV and Storage Demo	Sodium Nickel Chloride	Commissioning	1	50 kW	130 kWh
2500 R Street	Lithium ion	M&V period	34	4.5 kW	10.7 kWh
PV Storage Retrofit	Lithium ion	Scoping	10	4.5 kW	10.7 kWh
PV Storage Firming Demo	Lithium ion	M&V period	1	500 kW	125 kWh
Commercial Customer Storage Demo	Lithium ion	Feasibility study; deployment pending	1	18 kW	20 - 30 kWh
Bulk Storage Demo	CAES	Siting and feasibility studies complete; cancelled	1	135 MW	32,400 MWh
Microgrid Storage Augmentation and Feeder Demo	Zn Br Flow	Cancelled	2	0.5 MW	3.0 MWh

SMUD PV & Smart Grid Pilot at Anatolia

Anatolia Demo – Storage Availability Stats for 2012

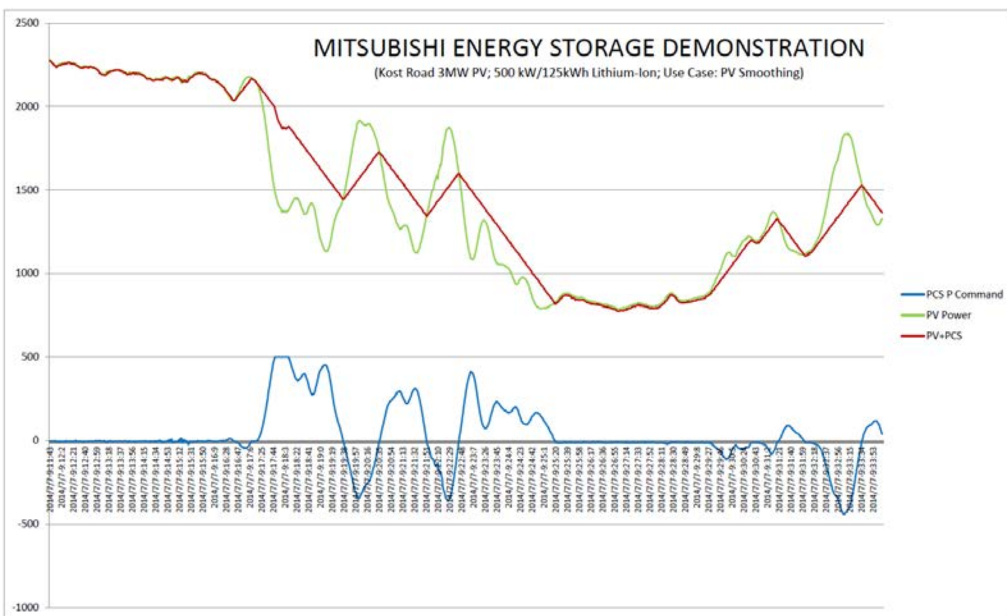
Storage System	Q2 Total Downtime (%)	Q3Total Downtime (%)	Q4 Total Downtime (%)
Residential	42%	36%	52%
Community	31%	21%	26%



- $5.9M Project ($4.3M DOE and $500k CEC) at Anatolia SolarSmart[SM] Homes Community
- Installed 15 RES (5kW/8.8kWh) and 3 CES (30kW/34kWh)
- Firmed renewables, shifted renewables and reduced peak load
- Partners included GridPoint, SunPower, Navigant, NREL, SAFT (lithium ion)
- Quantified costs and benefits of this storage deployment to gain insights to broader application for SMUD
- Status: project completed and systems decommissioned
- Application of Time of Use rates was a challenge when coupling energy storage and PV
- Systems durability not good; more development needed to improve performance

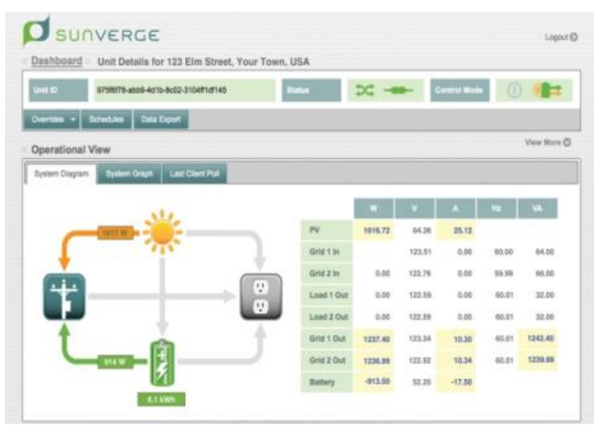
Acknowledgement: This material is based upon work supported by the Department of Energy under Award Number DE-EE0002066

SMUD Feed In Tariff PV & Storage Demo



- Storage to augment existing 3MW PV
- Partners include Belectric, Constellation, Mitsubishi Heavy Industries
- 500kW/125kWh lithium ion energy storage system
- Objectives
  - Minimize impact of PV variability
  - Control PV ramp rates
  - Help regulation voltage and mitigate sags
- Status
  - Installation completed in December
  - Commissioning underway
- Challenges with balance of system and telecommunications
- PV smoothing has been effective

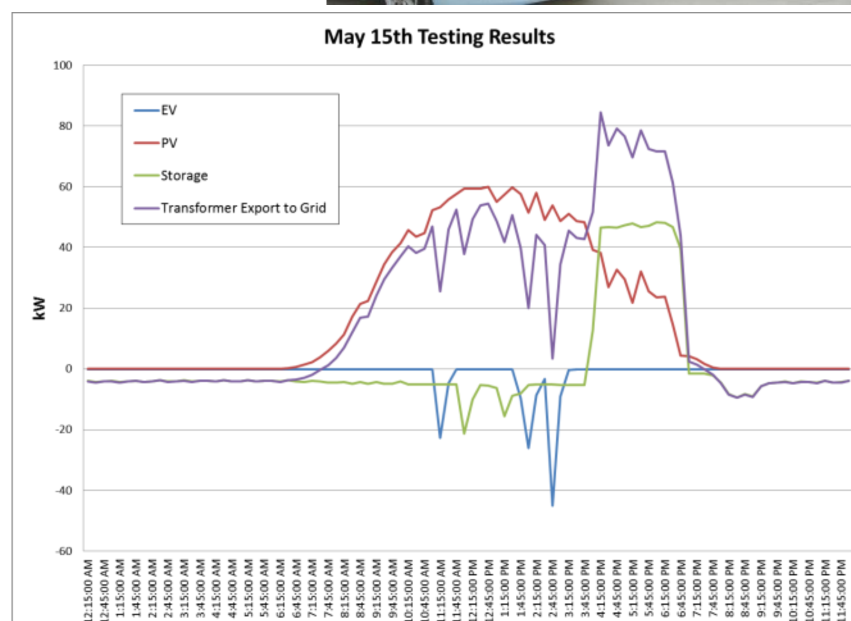
Residential Energy Smart Community Demonstration



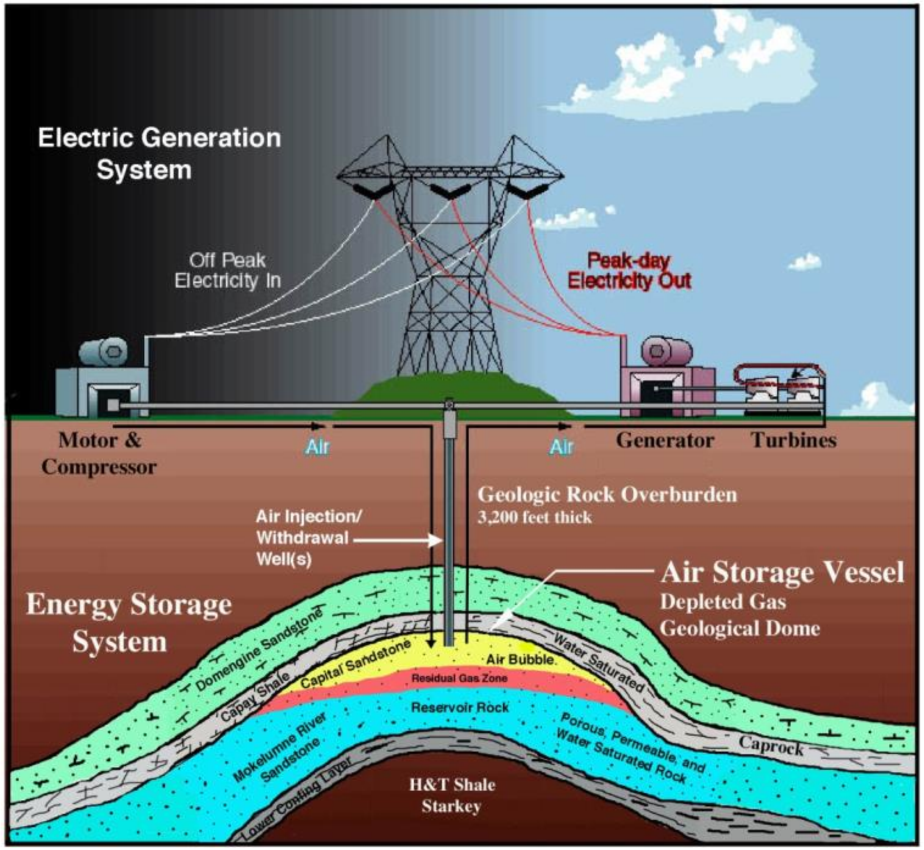
- Thirty-four SMUD SolarSmart Homes with better than 25-40% efficiency over standard homes
- PV, smart thermostats and plug controls, HAN, lithium ion storage (4.5kW/10.7kWh)
- Partners Pacific Housing, Sunverge
- $450k SMUD grant funded by DOE Assistance Agreement DE-OE0000214
- Objectives
  - Reduce demand and TOU charges through demand response
  - UPS functionality
  - Minimize impact of PV variability, control ramp rates
  - Peak load shifting
  - Real-time visibility and analytics of aggregated load for the utility
- M&V report will be completed at end of December

Solar EV Charge Port

- FIAMM NaNiCl 50kW/130kWh
- Objectives
  - Minimize impact of PV variability
  - Control PV and EV charger ramp rates
  - Peak load shifting
- Challenges
  - NaNiCl systems relatively new for utility applications
  - Battery capacity and usage must be partitioned to address multiple use cases simultaneously
  - Real time monitoring between the ESS and service transformer allows the storage system to “see” PV production and electric vehicle charging loads (gives system autonomous decision making ability for firming and dispatch)
- Status
  - Systems installed successfully
  - Integration with 50kW Parker inverter and Greensmith site controller complete and in final commissioning and testing phase
  - Recently, battery charge control problem rendered batteries unusable; evaluating options for replacement in order to continue demo

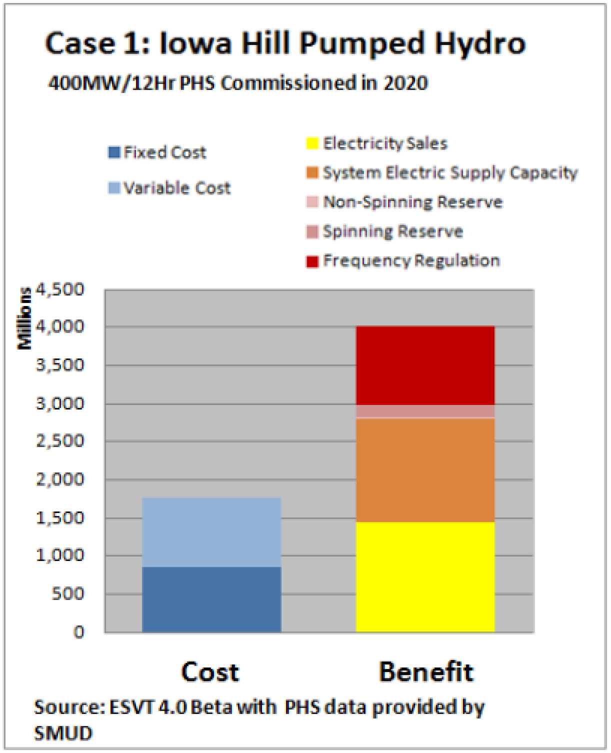


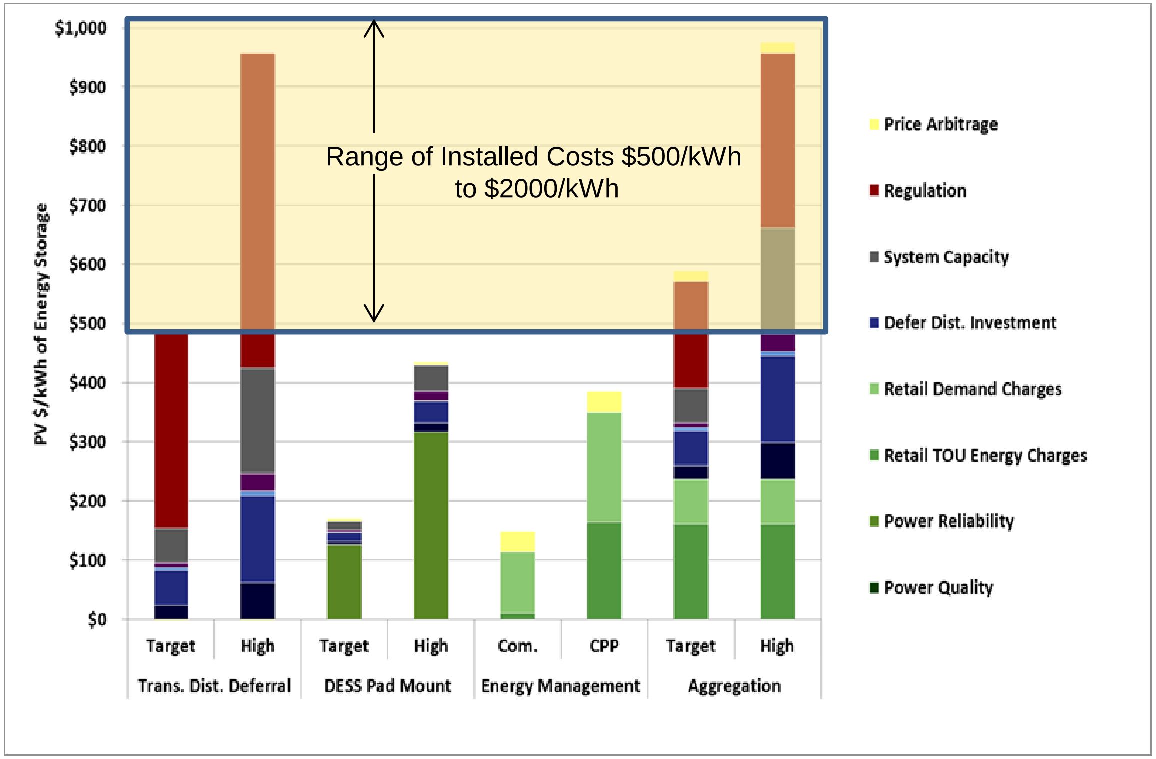
Compressed Air Energy Storage



- Investigated CAES to mitigate variability of wind and PV; also considered seasonal arbitrage
- Geologic risks include: fuel/air mixing, reservoir integrity, reservoir pressures, porosity and permeability of storage media, withdrawal and injection requirements, size of the structure
- Capital costs ($/kW) same magnitude as pumped hydro storage
- Value of weekly CAES comparable to Iowa Hill pumped hydro storage project
- Absence of operational experience of CAES plant with depleted gas storage field creates risks
- SMUD decided to discontinue CAES evaluation at the present time

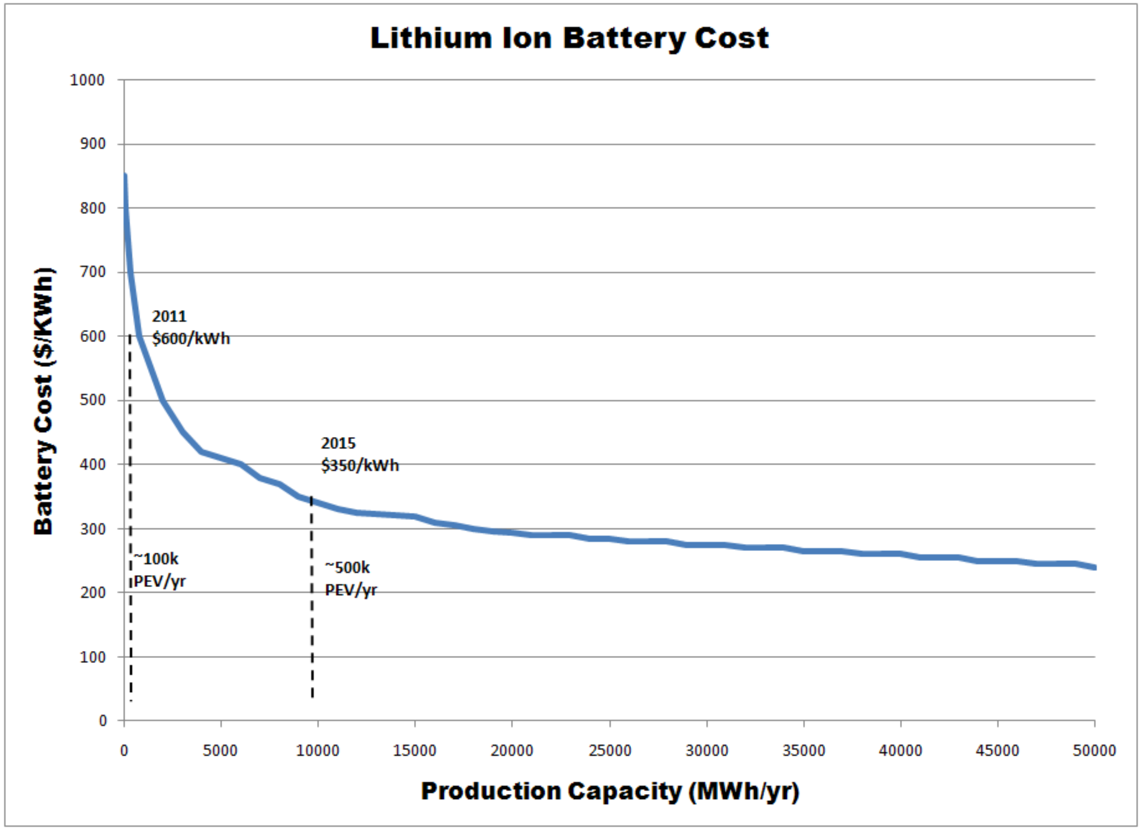
Only Bulk PHS Cost Effective Presently





- Extensive cost benefit analysis on Iowa Hill shows cost effective based upon current assumptions
- Distributed storage technologies not yet cost effective

Expected Cost Reductions For Li+



Note: Best fit curve for a family of Li-ion cost projections, including ANL (2009), EPRI (2007), Miller (2006), CARB (2007), and TIAX (2009)

- Source: **Lithium-ion Energy Storage Market Opportunities,** *Application Value Analysis and Technology Gap Assessment,* **EPRI Publication Number 1020074**
- Production of 1,000 MWh of PEV batteries per year would result in $600/kW-h (100,000 vehicles assuming 20kW-h per battery; $12,000 PEV battery pack)
- Production of 10,000 MWh of PEV batteries per year would result in $350/kW-h (500,000 vehicles; $7,000 PEV battery pack)

- Cost estimates in-line with projections provided to EPRI by leading Li-ion battery vendors for 2011 and 2015.
- Future stationary applications for lithium-ion can be on order of $400/kW-h (includes balance of plant costs for power electronics and utility interconnection)

Conclusions

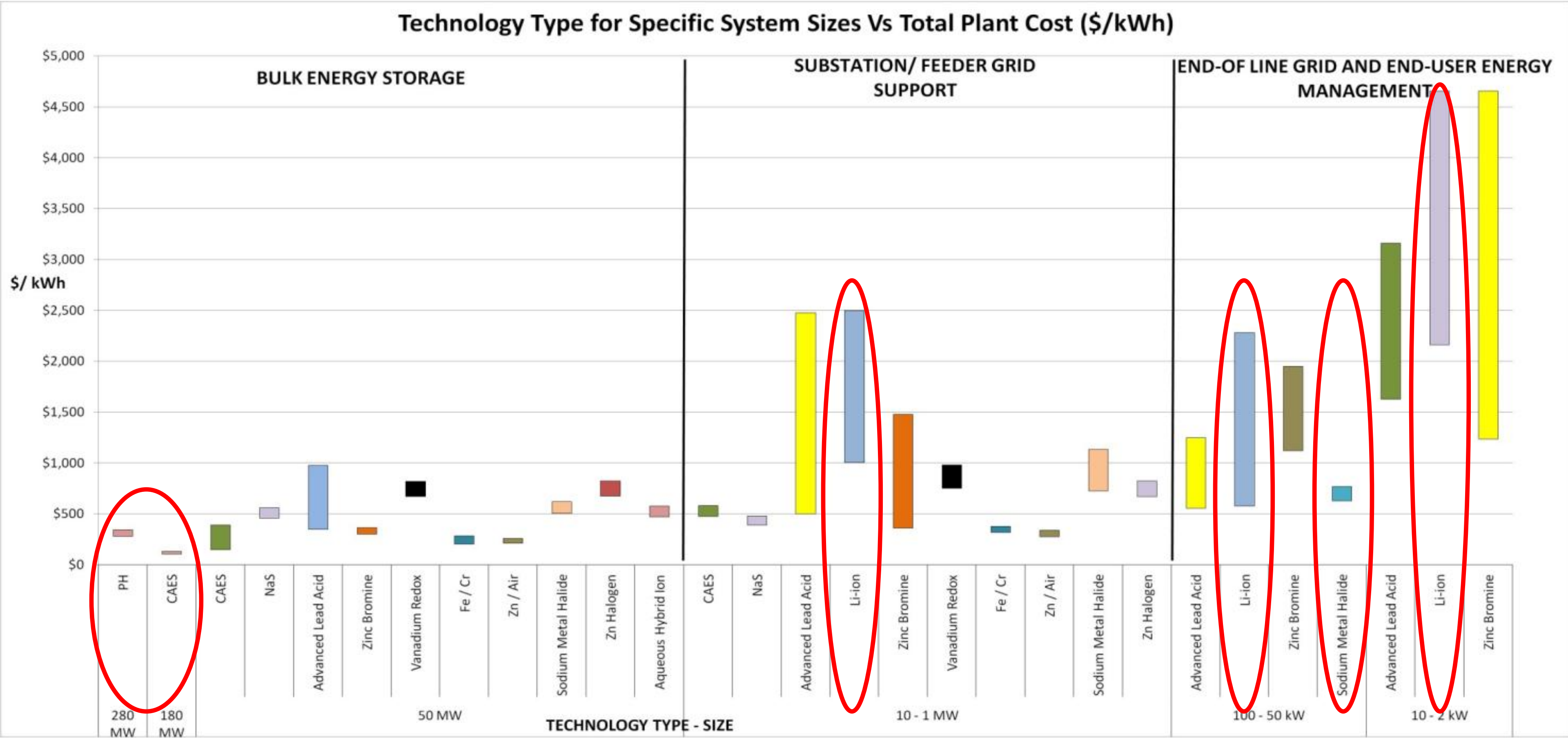
- Research pilots have provided SMUD valuable insights into siting, grid interconnection, telecommunications, control, and technology performance and readiness
- Battery costs continue to decline as global production capacity increases and vendors gain real world deployment experience
- Utilities and vendors need to work together to standardize application functional requirements, equipment and controls, test procedures and grid integration practices
  - Cofunded, founding member and on board of MESA
  - Cofunded and participating in EPRI ESIC
- Value analyses show distributed energy storage systems not yet cost effective given SMUDs avoided costs and rates
- Expect that distributed energy storage will become cost effective within next ten years
- Research efforts are preparing SMUD for storage to become part of customer and utility resource solution

MESA
Open Standards for Energy Storage

EPRI | ELECTRIC POWER RESEARCH INSTITUTE
Energy Storage Integration Council

Backup

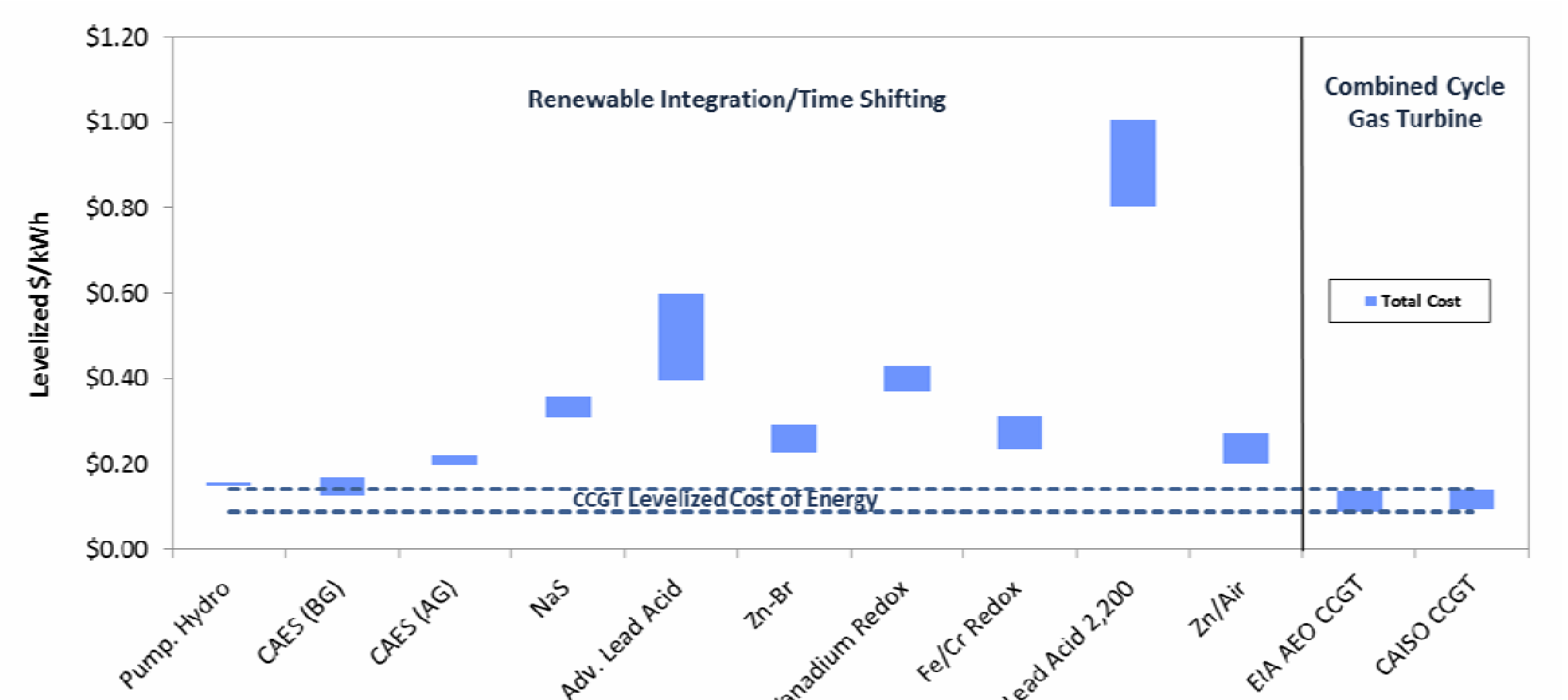
Projected Installed Costs By Application



Source: EPRI, 2012

- Highlights are technologies and applications SMUD has been assessing
- Not life cycle costs; these are installed costs divided by storage system duration
- Includes energy storage system, balance of plant, installation and contingencies
- These costs are based upon vendor interviews by EPRI and projections for commercial costs
- Technologies shown are at varying levels of development – first-of-a-kind systems will be higher

Lifecycle Cost Comparisons



Source: EPRI, 2010

Data shows distributed storage technologies still considerably higher than bulk storage or conventional gas turbines

Notes:

- Comparison: EE levelized costs $0.015/kWh - $0.109/kWh; PV levelized costs $0.13/kWh - $0.16/kWh
- Lithium ion estimated to be about 50% higher that Zn-Br flow batteries due to higher first costs (est. $0.37/kWh – $0.45/kWh)
- Includes capital and annual O&M; for emerging storage technologies uncertainty on assumptions
- Assumes storage completes one cycle per day
- Levelized costs calculated by dividing annual cost by annual generation